Land-Atmosphere Memory Quantified Using Observations from the Oklahoma Mesonet and the NOAH Land Surface Model

Year 1 Progress Report

Submitted by,

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Proposal Summary

The research project is designed to quantify the impact of soil water and vegetation on atmospheric processes. The Oklahoma Mesonet allows unique data sets of observations of surface fluxes of moisture and heat, skin temperature, and soil moisture to be generated. This network of over 100 hydrometerological stations encompasses all of Oklahoma. The application of such data permits detailed investigation of moisture and energy fluxes across variable vegetation, climate, and terrain conditions. The results of this investigation will increase our understanding of the role of surface features in atmospheric processes within the planetary boundary layer (PBL). Through the increased understanding of near-surface soil and atmospheric parameters, the NOAH land surface model (NOAH LSM) will be improved to aid in better forecasting of mesoscale interactions (such as the land breeze), convective initiation, and quantitative precipitation forecasting (QPF) through coupled land-biosphere-atmosphere models.

The primary objectives of the project are:

- Develop a quality controlled data set which involves meteorologic and hydrologic observations from Oklahoma Mesonet sites. Obtain new insights of land-atmosphere interactions from diagnostic studies using Mesonet data.

- Quantify the impact of observed variability in soil hydraulic properties within the NOAH LSM and explore the utility of ensemble techniques in the NOAH LSM in forecasting atmospheric processes within the PBL.

- Identify the parameterizations in the NOAH LSM which are sensitive to land surface conditions. Using Mesonet data, the parameterizations will be modified, improved, and tested to produce reduced model variability.

The collected Mesonet observations will be the basis for obtaining new insight into the role of surface conditions in modification of the PBL. Furthermore, the data will be used to validate, develop, and improve the NOAH LSM and models relating to the transport of heat and moisture within the PBL. In particular, this study seeks to improve the parameterizations which govern the evaporative fluxes from the land surface and the vegetation canopy. Investigations will also focus on model validation across multiple climate, vegetation, and terrain features.

The potential impact of the project on the development of the sciences of hydrology and meteorology lies in the improvements made to the assessment of surface characteristics of surface fluxes, temperature, and soil hydraulic properties using numerical weather prediction models which predict the timing and onset of precipitation. Until now, few measurements have been available, especially soil moisture, over such a large region at high spatial and temporal resolutions. Proper validation is essential in providing accurate estimates of surface conditions on all time scales needed in hydrological and meteorological modeling. Thus, the proposed study is critical to continuous improvement of numerical weather prediction models.

Year 1 Activities and Results

During Year 1, the research focused on the first and third objectives of the proposed research.

Objective 1:

The first objective of this study is to *develop a quality controlled data set which involves meteorologic and hydrologic observations from Oklahoma Mesonet sites and obtain new insights of land-atmosphere interactions from diagnostic studies using Mesonet data.* A number of research activities were undertaken during Year 1 to accomplish this objective.

Mesonet Data for the GAPP community

Support for Year 1 included the development of datasets for the GAPP and NASA research community. As such, archived standard Mesonet data and soil moisture data were processed and quality assured (QA'd) for 2001, 2002, and portions of 2003 (January – April). The datasets were subsequently transferred to the CODIAC database for use by GAPP and NASA scientists.

Total data values transferred to the CODIAC database for the 2001-2003 period during Year 1 includes:

- Over 200 million standard Mesonet observations
- Approximately 14 million soil moisture observations

Diagnostic Studies of Land-Atmosphere Interactions Using Mesonet Data

Funding for Year 1 supported a number of diagnostic studies that involved Oklahoma Mesonet data. For example, the impacts of short-term droughts in Oklahoma were analyzed by Illston and Basara (2003). The study focused on droughts that occurred during years of above-annual precipitation (1998 and 2000) using Oklahoma Mesonet data. The results demonstrated the importance of analyzing droughts at reduced time scales (months) using observational data and modeled drought indices. While yearly analysis of hydrological conditions is important, many short-term droughts may be overlooked in this process. It was shown that while drought indicies are capable of analyzing the location of severely depleted soil moisture conditions, they do not consider anomalies of soil moisture values. Additionally, this study found that time of the year of the short-term droughts is critically important how certain crops are affected by drought conditions.

Another study investigated the surface skin temperature measurements installed at Oklahoma Mesonet sites (Fiebrich et al. 2003). In 1999, the Oklahoma Mesonet deployed infrared temperature (IRT) sensors at 89 of its environmental monitoring stations. A 3-year dataset provided a unique opportunity to analyze longer-term, continuous, mesoscale observations of skin temperature across a large area. The

diagnostic study was also able to identify several limitations of the sensor including: (1) failure of the calibration equation during the cold season, (2) difficulty in keeping the sensor's lens clean at remote sites, and (3) limited representativeness of local conditions due to the sensor's narrow field of view. Despite these limitations, the Oklahoma Mesonet's skin temperature network provides a wealth of information that can be used to better understand many land-atmosphere interactions. Not only can the observations be used to estimate the partitioning of latent and sensible heat flux, they also provide beneficial "ground truth" estimates to validate remotely sensed estimates of skin temperature as well as numerical model simulations of surface skin temperature (e.g., NOAH). The Fiebrich et al. (2003) manuscript describes the IRT sensor, evaluates its performance, and provides analysis of time series data and observed spatial variability across Oklahoma.

Development of Research Datasets for NOAH validation

The creation of the dataset for model validation initially focused on observations collected at the Norman (NORM) Mesonet site during 2000. Originally, the 5-minute data were not quality assured. However, missing data were designated in each file. The primary observations included net radiation, downwelling shortwave radiation, reflected shortwave radiation, downwelling longwave radiation, upwelling longwave radiation, sensible heat flux, latent heat flux, and ground heat flux.

Initially, daily time-series plots of net radiation were analyzed to identify “candidate days.” Candidate days are days consisting of little or no cloud cover and at least 95% useable data points. Once candidate days in 2000 for NORM were determined, time series plots showing net radiation, latent heat flux, sensible heat flux, and ground heat flux were created for these days. An example of a time series plot showing a typical “sunny-day” profile, and a time series plot showing the net radiation and land-surface flux components of the surface energy budget can be seen in Figure 1. A total of 51 days met the criteria for sunny days with little cloud cover at NORM during 2000.

The heat flux and radiation data were subsequently averaged (15 and 30 minute intervals) for all 51 days. Figure 2 displays an example of these plots using the same data as the plots in Figure 1. Next, heat flux and radiation data were obtained for the other 9 OASIS Super Sites and compared with the dates in 2000 obtained for NORM. Using these dates for the other sites, as well as an examination of all remaining dates in 2000, a total of 475 candidate days were identified across the network.

Initial quality-assurance methods were then developed to find any errors associated with the OASIS flux data. First, some candidate days with concurrent dates at all ten OASIS Super Sites in 2000 were examined. The data were quality assured by visually inspecting the radiation and heat flux time-series plots for each site while scanning the data one observation at a time to assign quality assurance flags to the data. The quality assurance flags given to the data were as follows: 0 = good, 1 = suspect, 2 = warning, 3 = bad

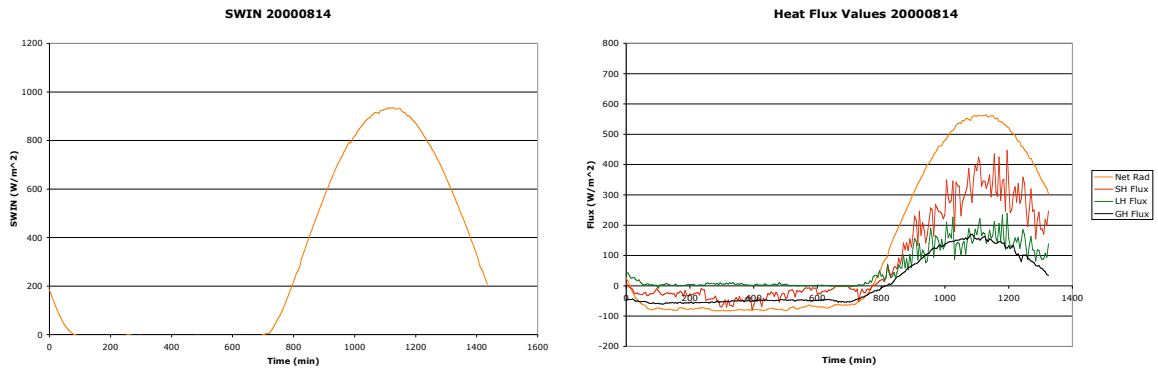

Figure 1. Time Series Plots of Net Radiation and Components of the Surface Energy Budget at the NORM Mesonet Site for August 14, 2000.

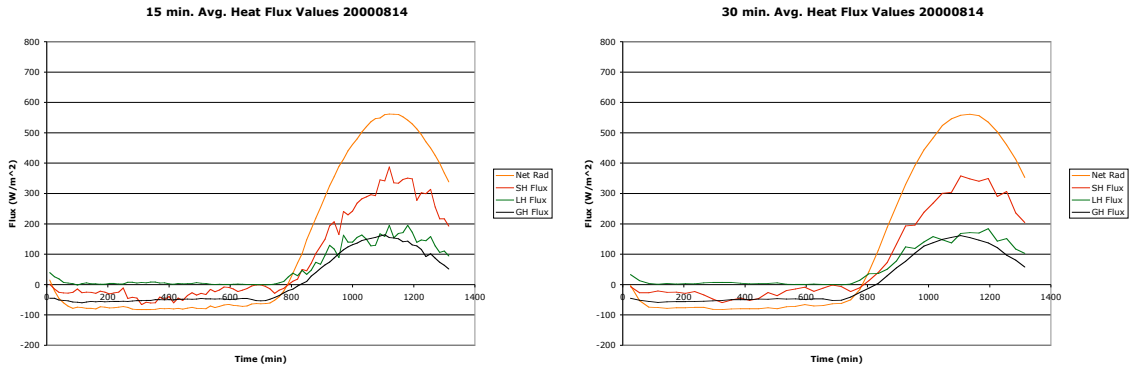

Figure 2. The 15-minute and 30-minute Average Time-Series Plots of Net Radiation and Components of the Surface Energy Budget at the NORM Mesonet Site for August 14, 2000.

or missing data. The visual inspection also resulted in the assignment of rigid boundaries for the QA process. The boundaries are as follows:

For nighttime observations of latent, sensible or ground heat flux values:

- Any value with a magnitude between 50 and 75 W m^{-2} was flagged with a value of 1.
- Any value with a magnitude between 75 and 100 W m^{-2} was flagged with a value of 2.
- Any value with a magnitude greater than 100 W m^{-2} was removed and flagged with a value of 3.

For daytime observations of sensible or latent heat flux values:

- Any value with a positive value between 450-475 W m^{-2} was flagged with a value of 1.
- Any positive value between 475-500 W m^{-2} was flagged with a value of 2.
- Any positive value greater than 500 W m^{-2} was flagged with a value of 3 and removed.

Ground heat flux values rarely rose above 150 W m^{-2} during the day, and were thus not included in the daytime QA analysis. Likewise any latent, sensible, or ground heat flux values that fell below 0 during the daytime period were flagged. However, the assignment of this QA flag was more subjective, and no hard boundary has been determined.

Additional methods for determining quality assurance flags included step tests between observation points. Again, these flags were subjective and no definitive step test has been determined. Also, latent heat flux values depended upon output from the sonic anemometer which is used (in part) to measure sensible heat flux values. As such, it was necessary to concurrently flag latent heat flux values if the sensible heat flux measurements were flagged.

Using the described methodology, 17 days were QA'd that include data from all ten OASIS Super Sites during 2000 along with 6 additional days in 2001. Due to the tediousness of these quality assurance procedures, automated methods are being developed to quality assure the Super Site data. Because this data has been collected and archived from 1 June 1999 until the present date for ten sites, there are possibly thousands of research-quality candidate days still waiting to be analyzed.

Objective 3:

The third objective of the study is to i*dentify the parameterizations in the NOAH LSM which are sensitive to land surface conditions and use Mesonet data to modify, improve, and test the parameterizations to produce reduced model variability.*

A retrospective simulation data set for the NOAH land-surface model was provided in collaboration with Dag Lohmann at NCEP for the 1999-2000 period. A new land/sea mask, composed of the 11 grid points located closest to the 10 OASIS Super Sites, was created. It was necessary to use 11 grid points, because the Boise City site was located directly between two grid points.

The model simulated energy fluxes were compared with the OASIS surface flux data set, which includes net radiation, latent heat flux, sensible heat flux, and ground heat flux for the following days: 23 May 2000, 29 May 2000, 30 May 2000, 10 July 2000, 13 August 2000, 14 August 2000, 25 August 2000, 29 August 2000. Time series plots were created for each day at each OASIS Super Site to compare the time-averaged hourly output to the hourly averaged flux observations.

The results of the comparison between NOAH and OASIS fluxes are shown in Figure 3. Overall, the preliminary analyses show good agreement between the observed and modeled values of net radiation and are consistent throughout the data set for each Super Site. The modeled and observed net radiation curves follow the same diurnal pattern. However, the NOAH net radiation curve reaches its peak value slightly before the observed net radiation curve. In addition, the observed net radiation typically was greater in magnitude at the peak value than the modeled values. The only site that did not follow this trend was Burneyville (BURN), where the modeled peak net radiation was greater than the observed peak net radiation.

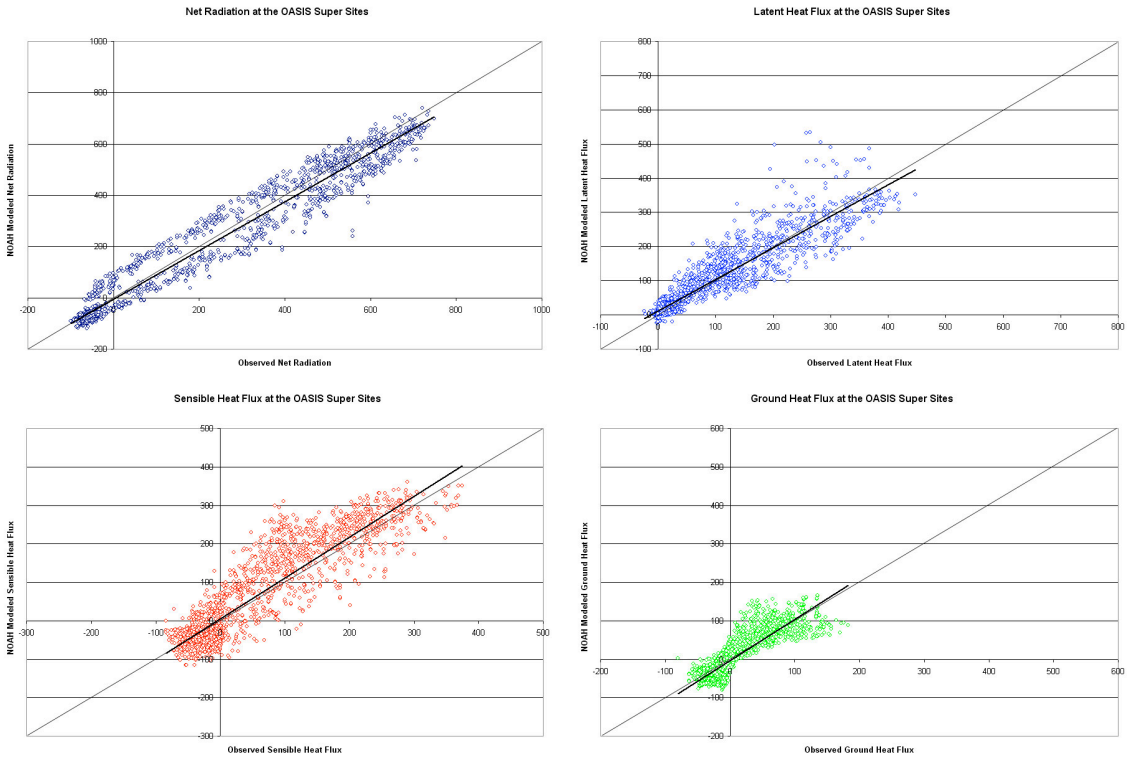

Figure 3. NOAH modeled and observed surface fluxes for all OASIS Super Sites.

The results for latent heat flux were not as consistent as those for net radiation. While the NOAH modeled and observed latent heat fluxes follow the same temporal pattern, it was not uncommon for the modeled latent heat flux curve to reach its peak value earlier than the observed. The results also reveal a slight underestimation of latent heat flux by the NOAH compared to observations collected across Oklahoma.

The results of the sensible heat flux analyses show significant agreement between observed values and estimates from the NOAH model. Even so, the majority of the intercomparisons at specific sites revealed that modeled sensible heat fluxes were greater than the observed values. However, these differences decreased from May to August

2000 as the overall magnitude of sensible heat flux increased. Overall, the Stigler site (STIG) displayed the largest differences during May 2000.

The ground heat flux values computed by NOAH also compared well with OASIS observations. However, particular trends were observed at specific sites. For example, the modeled ground heat flux values are larger than those observed at the Alva site, while the opposite is true for the Norman and Stigler sites. Like the sensible heat flux analyses, the differences decreased as the summer progressed.

The preliminary validation of the NOAH modeled surface energy fluxes using OASIS data provides a blueprint for future work. In terms of a regional approach, these preliminary results show that net radiation is captured very well, sensible heat flux is overestimated, latent heat flux is underestimated, and ground heat flux was slightly overestimated. Further investigations of additional candidate days and closer inspection of individual sites will allow for a more complete validation effort. In turn, NOAH model performance will be improved.

Miscellaneous Activities:

- Jeff Basara and Kodi Nemunaitis attended the Mississippi River Climate Conference in May 2002. Jeff Basara presented a research paper entitled *The Oklahoma Mesonet: An Infrastructure for Land-Atmosphere Interactions.*

- Jeff Basara, Kodi Nemunaitis, and Brad Illston attended the Annual Meeting of the American Meteorological Society in February 2003. Jeff Basara presented a research paper entitled *The Representativeness of Skin Temperature Measurements at Oklahoma Mesonet Sites*. Brad Illston presented a research poster entitled *Climatology of Soil Moisture Variables Using the Oklahoma Mesonet*. Kodi Nemunaitis presented a research paper entitled *The Validation of a Land Data Assimilation System (LDAS) Using Data from the Oklahoma Mesonet.*□

- Jeff Basara, Ken Crawford, Kodi Nemunaitis, and Brad Illston traveled to NCEP in April 2003 to discuss strategies for NOAH validation using the Oklahoma Mesonet. The group also attended the LDAS PIs meeting at NWS Headquarters and provided insight on the application of Mesonet data for LDAS validation and improvement.

Future Work:

The efforts of Year 2 will build upon the groundwork laid by the efforts of Year 1. These include the following:

- Continue validation of the NOAH land surface model using Mesonet/OASIS data.

- Continue development of datasets used for NOAH validation and improvement. Continued identification of candidate days for study.

- Begin the transition to NOAH model improvement once specific parameterizations are identified for further analysis.

- Perform additional diagnostic studies focused on Mesonet soil moisture data, skin temperature data, and OASIS surface flux data.

Based on the success of Year 1 of the research project, the Principal Investigators request the proposed funding for Year 2 in order to continue the research project.

Publications:

Basara, J. B., R. A. McPherson, D. S. Arndt, B. G. Illston, M. J. Haugland, C. A. Fiebrich, and K. C. Crawford, 2002: The Oklahoma Mesonet: An infrastructure for quantifying land-atmosphere interactions, *Mississippi River Climate and Hydrology Conference*, New Orleans, LA, 17.

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Fiebrich, C. A., J. E. Martinez, J. A. Brotzge, and J. B. Basara, 2003: The Oklahoma Mesonet's skin temperature network. *J. Atmos. Oceanic Tech.*, in press.

Illston, B. G. and J. B. Basara, 2003: Analysis of short term droughts in Oklahoma. *EOS, Trans.*, AGU, **84**, 157, 161.

Illston, B. G. and J. B. Basara. 2003: Climatology of soil moisture variables using the Oklahoma Mesonet. Preprints, 17th Conference on Hydrology; American Meteorological Society, Long Beach, California, February 9-13.

Nemunaitis, K. L. and J. B. Basara, 2003: The Validation of a Land Data Assimilation System (LDAS) Using Data from the Oklahoma Mesonet. Preprints, 17th Conference on Hydrology; American Meteorological Society, Long Beach, California, February 9 - 13.